HETERO-INTERFACES FOR EXTREME ELECTRONIC ENVIRONMENTS

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- Quasi-two-dimensional electron gas in oxide based hetero-interfaces:
  → Recently discovered (2004) → Tunability (2006)
- Investigated for nano-device applications (i.e, non-volatile memory)
- Extreme environment applications are possible
  - Incorporation of ultra-thin high-K dielectric (dielectric constant, K=25) film that eliminates the need for a gate dielectric.
  - Insulating film and the substrate increases radiation hardening
- The science behind Q-2D-EG and its tunability is still not clear.
  1- Polar catastrophe at the polar LAO/non-polar STO interface, 2- structural distortions at the interface, 3- oxygen vacancies introduced into the LAO/STO hetero-structure during the growth of LAO, 4- preferential cationic intermixing at the interface.
- A large number of parameters can effect both the existence and the magnitude of the interface conductivity.
  - Substrate quality
  - Film composition
  - Defects
  - Strain development
  - Film thickness
  - Electrode materials
  - Film surface conditions
  - In plane anisotropy.

All have different dependence on temperature. Therefore any extreme environment application requires quantitative analysis of these parameters.

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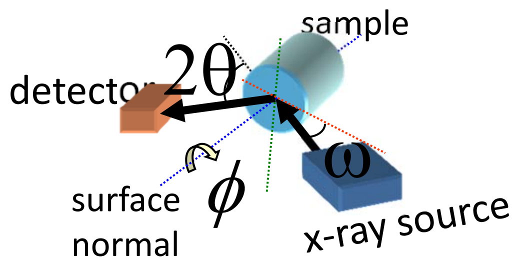
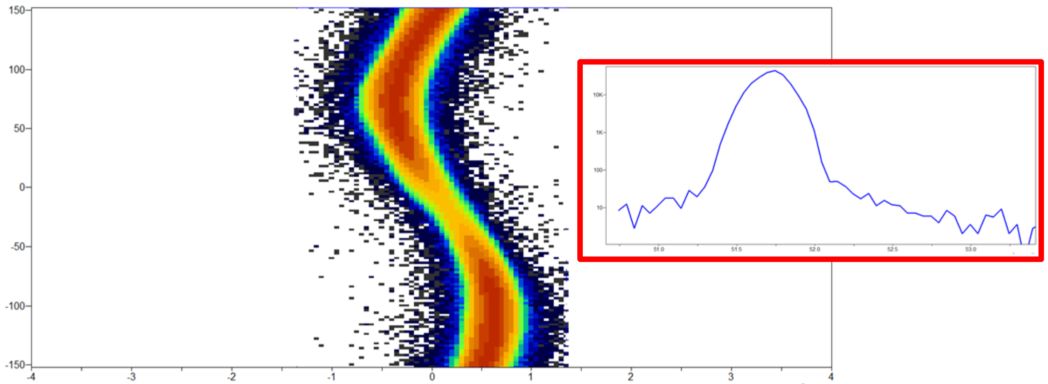
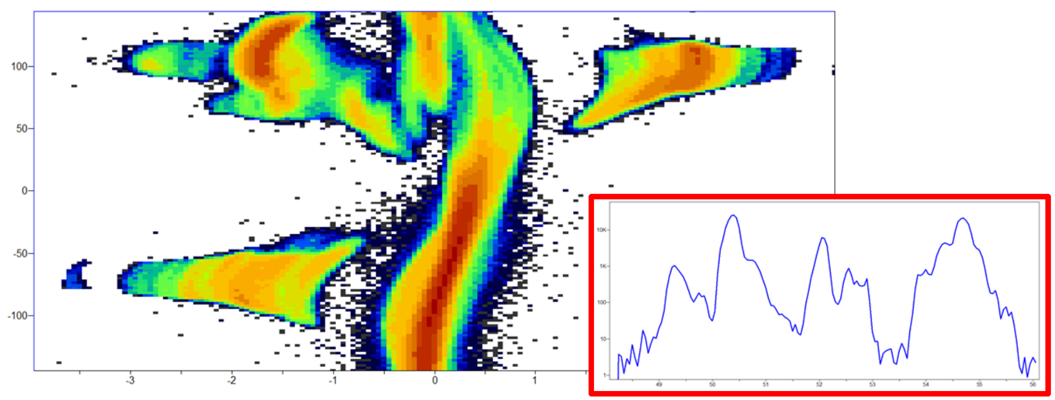
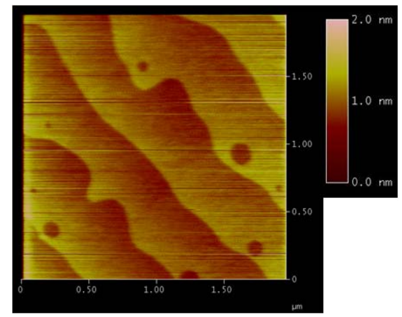
Substrates



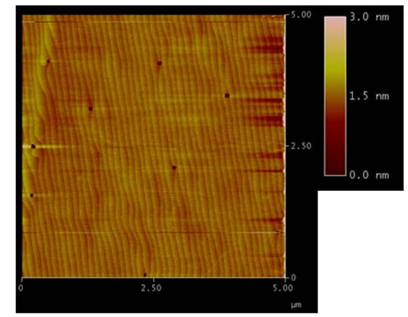




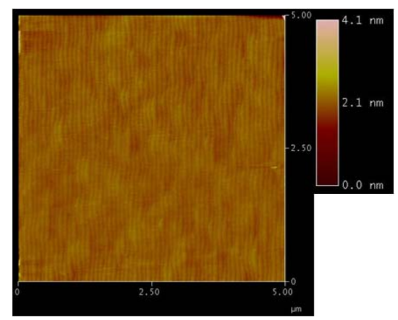
Commercial finishing
with etch pits



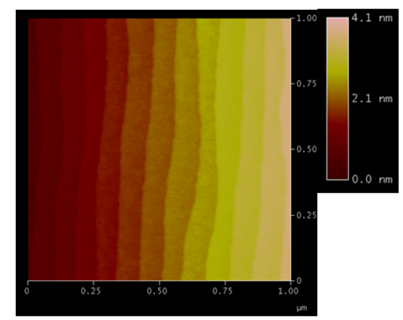
Our finishing
with etch pits at pH =5.7



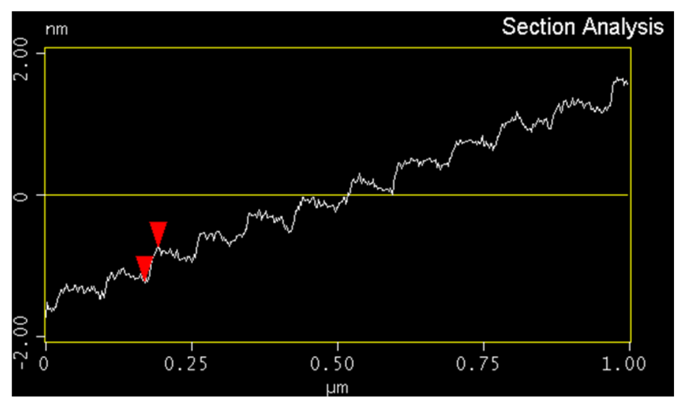
Etch pit free
surfaces at pH =5.7



Profile showing
the flat terraces



4Å steps = unit cell size (Ti-terminated)



- Substrate quality depends on the company
- The curvature is due to the mis-cut angle

  Larger the mis-cut angle, narrower the terraces (AFM)
- ~4Å steps = unit cell size (Ti-terminated)
- Commercially prepared surfaces show etching pits.
- We showed that at pH=6 we can get etch pit free surfaces

Reciprocal space mapping

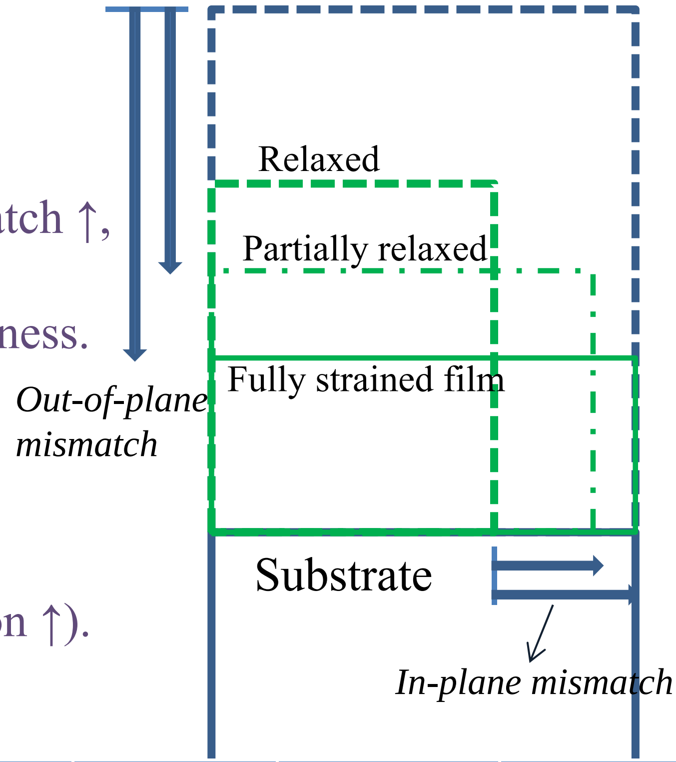
Bulk LAO: 0.3791 nm   Bulk STO: 0.3905 nm

In-plane direction:

- $LaAlO_3$ films are under tensile strain.
- As thickness increases: Stress ↑ , Lattice constant ↓ , Mismatch ↑, Strain ↓
- Partial relaxation in $LaAlO_3$ films with increasing film thickness.
- Above 80nm film thickness: Plastic deformation due to large strain. Residual film remains highly strained.

Out-of-plane direction:

- $LaAlO_3$ films are tetragonally distorted.
- Degree of tetragonality is decreased as thickness ↑ (relaxation ↑).
- Residual film above 80nm is still tetragonally distorted.

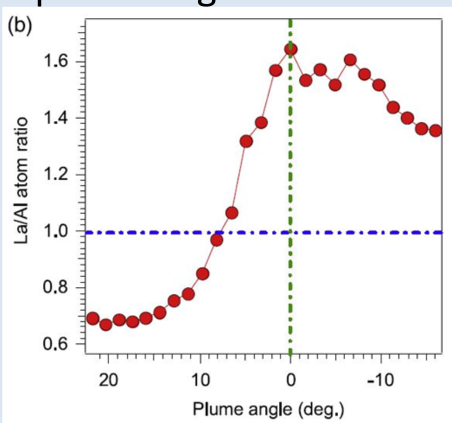


Wei Wei and Alp Sehirlioglu, Appl. Phys. Lett., **100, 071901 (2012)**

Laser pulse	Thickness (nm)	f_{pp}	f_{pl}	ε_{pp}	ε_{pl}	$a_{pp\ (nm)}$	$a_{pl\ (nm)}$	Relaxation rate	a_{pp}/a_{pl}
100	4.9	- 0.03958		- 0.00913		0.375045			
200	7.9	- 0.03522	- 0.00056	- 0.00437	0.03139	0.376750	0.390280	1.83%	0.965332
500	18.3	- 0.03358	- 0.00076	- 0.00268	0.03119	0.377390	0.390202	2.48%	0.967165
1000	38.4	- 0.03326	- 0.00100	- 0.00261	0.03067	0.377513	0.390109	3.26%	0.967711
1500	65.4	- 0.02987	- 0.00117	- 0.00321	0.03050	0.377284	0.390041	3.83%	0.967293
2000	84	- 0.03322	- 0.00052	- 0.00257	0.03117	0.377529	0.390298	1.68%	0.967283

Composition

La/Al ratio in the film and the level of intermixing can depend on plume angle

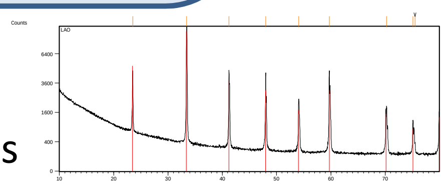


T.C. Droubay, et al. Appl. Phys. Lett. **97**, 124105 (2010).

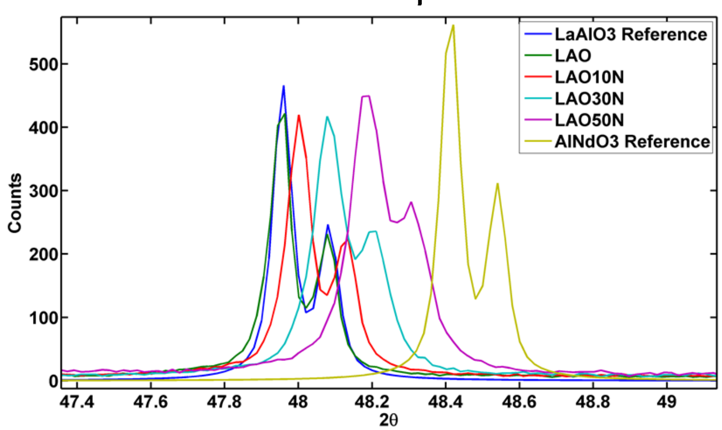
➢The composition of target and the film can be different when multiple single-site cations exist.

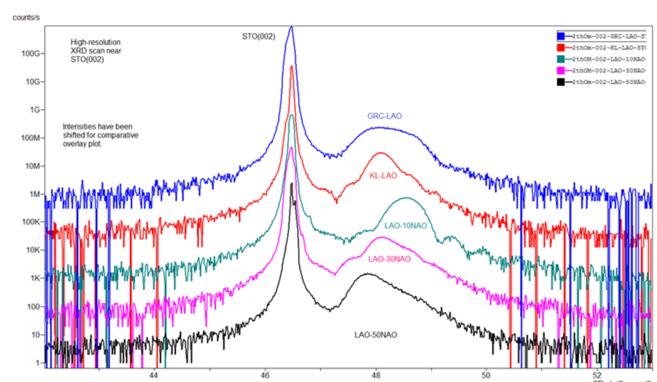
➢ The composition of the film can be different for targets of same composition but different source.

Sample	O	La	Nd	Al	(La + Nd)/Al	Nd/La
LAO-CWRU	66.13	20.25	0	13.62	1.48	0
LAO-Kurt Lesker	62.85	25.93	0	11.22	2.31	0
LAO-10NAO	67.03	18.88	0.69	13.39	1.46	0.036
LAO-30NAO	67.38	18.13	5.14	9.35	2.48	0.28
LAO-50NAO	65.93	15.54	8.97	9.56	2.56	0.57



Single phase targets with controlled lattice parameters





Film lattice parameters and composition do not follow that of target.